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Growing of Greenhouse Tomatoes

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GROWING OF GREENHOUSE TOMATOES

I. C. HOFFMAN

Tomato culture under glass has become a large industry in Ohio. Many cultural practices that seem to be unprofitable have come into vogue with commercial growers, and there is need for a critical examination of them, as well as a searching for better ones. This bulletin reports a series of experiments conducted in the Station greenhouses at Wooster and also in some commercial houses in the vicinity of Cleveland. It concludes studies of the best time of sowing seed, the effect of holding tomato plants in pots, distance of planting, leaf pruning, mulching, fertilizing during the fruiting period, and potted versus trowel-set plants.

TIME OF SOWING TOMATO SEED

Greenhouse tomato growers have varied the time of sowing the seed for the early spring crop in past years so as to fit it into a lettuce growing system. Since the trend now is towards a longer tomato growing season, the crop is being planted earlier than formerly. The question of the time of sowing the seed to secure the largest crop has been raised. In order to supply a definite answer, a comparison of the yield and behavior of tomatoes sown early in December and January, respectively, in the same season was made. The results given in Table 1 show a decided increase in the crop sown early. The early planting had ripe fruits a month earlier than the later planting and, furthermore, continued to bear fruit as long as the late planting.

TABLE 1.—Time of Sowing Tomato Seed

Date of sowing	Date set	First picking	Last picking	Picking season	Av. yield per plant	Difference
				Days	*Lb.*	*Per cent*
Dec. 3, 1929	Feb. 4	May 17	July 31	76	10.63	26.5
Jan. 3, 1930	Feb. 18	June 17	July 31	45	8.40	....

This experiment was repeated and enlarged to four planting dates. Seed was sown in flats December 1, 15, January 1, and 15, respectively. As soon as the plants were up, they were transplanted into soil in flats, spaced 2 inches by 2 inches, and grown until they covered the ground. At this time, they were again transplanted into 4-inch pots and grown to about 6 or 7 inches high, when they were set into the bed. (See Fig. 1). The plants were treated similarly throughout the rest of the season, and the method of culture was approximately the same as that of any good commercial grower. This experiment was conducted for 2 years, and Table 2 presents typical results of both years on the growth of the plants from seed sowing throughout the life of the crop, as well as yield data.

Fig. 1.—Potted plants similar to these were used for these investigations

The variety used was Marhio, a large pink sort of the Marglobe type and second early in season. The fruits ripened in the earliest sown lot in 56 days from blooming. In the remaining sowings, the first fruits ripened in 51 days in each case. It has been known for a long time that it takes longer to raise tomatoes or, in fact, most vegetable plants under the short-day and low-light conditions of early spring than later when the conditions are more favorable. It was interesting to note that all of the lots had finished bearing at the same time and were removed from the bed on the same date. The day temperatures in the greenhouse during June 1931 rose very high—often from 90° to 100° F., and, as tomato buds and blossoms do not persist long when subjected to these high temperatures for a few days, the buds in the top clusters dropped. In addition to the high temperatures, the tomatoes were subjected to the longest days of the season. Continuous daylight periods of more than 14 hours tend also to prevent tomato buds from opening and setting fruit. So, the plants in the last sowing, particularly, were handicapped by these factors, as well as by late planting.

The yield data are presented in Table 2. It will be noted that the earliest sowings carried the largest number of fruits and matured the greatest weight per plant; consequently, they yielded the most per square foot of ground occupied. There is no significant difference in the average size of the fruits in either planting.

TABLE 2.—Time of Planting Greenhouse Tomatoes for the Spring Crop

Plot No.	Date seed sown	Date set in bed	Date blooming began	First ripe fruits	Days from blossoms to ripe fruit	Date last picking	Picking period	Yield per plant		Av. wt. of fruits	Yield per sq. ft.	Percentage first grade	Percentage decrease per plant below earliest planting
							Days	*No.*	*Lb.*	*Oz.*	*Lb.*	*Pct.*	*Pct.*
1.........	Dec. 1, 1930	Jan. 26	Feb. 12	Apr. 10	56	July 8	90	26	8.32	4.96	1.64	82.9	....
2.........	Dec. 15, 1930	Feb. 6	Feb. 27	Apr. 18	51	July 8	82	24	8.12	5.26	1.56	87.5	2.40
3.........	Jan. 1, 1931	Feb. 12	Mar. 9	Apr. 29	51	July 8	71	21	7.53	5.39	1.42	86.6	9.49
4.........	Jan. 15, 1931	Feb. 28	Mar. 21	May 11	51	July 8	59	18	6.20	4.97	1.11	89.2	25.48

In general, the fruits were all smooth and marketable. The earliest planting had a slightly lower percentage of first grade fruit than the rest, and the last planting produced the highest percentage of first grade fruit. There was no significant difference between the intermediate plantings in this respect, and the whole series of plantings presented what was believed to be a characteristic response to the growth factors as they were manifested at Wooster. From the results of these experiments, it seems that growers are justified in continuing the practice of sowing tomato seed about the first of December for the following spring crop. It not only brings the largest yields, but also the crop brings the highest price on the early spring market.

EFFECT OF HOLDING TOMATO PLANTS IN POTS AFTER REACHING PLANTING SIZE

Some growers have held tomato plants in pots too long after they have reached planting size for several reasons. Seed has been sown early in the winter for the spring crop anticipating a timely removal of the winter crop; sometimes there is a delay of a week or more in removing it, and the tomato plants may have to be held back by keeping them dry and cool. Other growers have felt that a certain "aging" of the plants was necessary and have held them back purposely for a week or more. But whatever the reason, under these conditions the plants become woody, hard, light colored, and often stunted. Sometimes they become tall, slender, and spindling if crowding is permitted. The roots are confined by the walls of the pots and are prevented from spreading normally. They grow around its inner surface and soon form a mass which becomes more or less injured and inactive by the unfavorable conditions. Where such stunting or crowding has occurred, deep planting or laying down of the plant so that only a few inches of the top stick out of the ground has been tried as an expedient, but in most cases the attempts have not been particularly successful.

In order to study the effect on yield and growth of holding tomato plants in pots for 1 to 4 weeks after they had reached planting size, the following experiment was set up. Four sowings of seed were made as indicated in Table 3. As soon as the seedlings were large enough they were transplanted to 4-inch pots, where they were held until planted in the permanent bed. Instead of planting each lot as soon as it was ready, as in the previous experiment, they were all held until the plants in the last lot were about 5 inches high. (See Fig. 2). Then all of the lots were transplanted the same day, February 17. The oldest lot of plants

(December 10) was near the blooming stage. Small buds could be seen in the apical portion of the plants, but, as yet, none of them had started to open. The plants in the second planting (December 16) were nearing the same condition. Those in the third and fourth plantings were of good size and condition. The plants in the first and second plantings were tall, slender, light colored, and woody; whereas the third and fourth plantings were stocky, dark green, and vigorous in appearance.

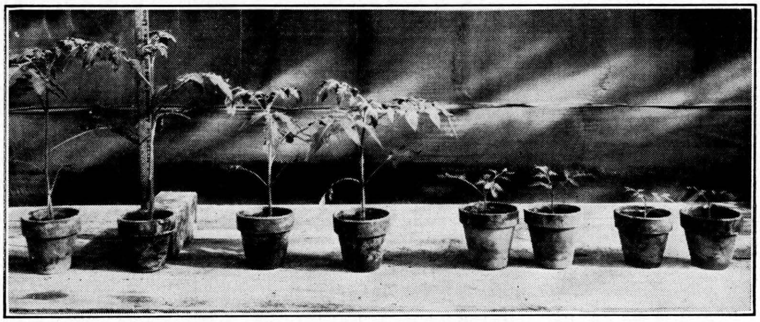

Fig. 2.—The effect upon yield of holding tomato plants in pots. Left to right, two plants each planted December 1, 15, January 1, and 15, respectively

The plants varied in size approximately as shown in Figure 2. Both lots of early plants produced ripe fruits on May 4 in nearly equal quantities. The January 4 and 13 plants produced their first ripe fruits May 11 and 16, respectively. In Table 3 it will be found that the plants in the December plantings produced as many fruits per plant as those planted in January, but the average weight per plant was considerably less. In average weight per fruit it will be

TABLE 3.—The Effect on Yield of Holding Tomato Plants in Pots

Date of sowing	Av. yield per plant		Av. weight per fruit	Percentage in first grade
	No.	*Lb.*	*Oz.*	*Pct.*
December 10	27.80	8.95	5.13	78.3
December 16	27.69	8.76	5.06	80.9
January 4	25.50	10.48	6.56	87.2
January 13	28.64	10.58	5.90	90.1

observed that those from the December plantings were appreciably smaller than those from the January plantings, and also the percentages of first grade fruits for the crop were considerably lower. An inspection of the plants and fruits during the season showed that the greatest difference in size and grade of fruits occurred on the lower clusters. Under the conditions of this experiment there was no loss of blossoms in any lot of plants, but the fruits produced varied in size considerably on the lower cluster, the fruits on the first and second clusters of the December plantings being much smaller than those on the later ones. Furthermore, they were not as smooth or as well developed as those on the later plantings. Later in the season there was no difference in the size and shape of the fruits, and they continued to be similar until the end of the season. The conclusion was drawn that early sowing, when followed by holding the plants for varying periods of time in pots under cool and dry conditions, was harmful to spring tomatoes. If the blossoms set, the fruits were usually small and often of poor shape, and the total yields for the season were very much reduced.

DISTANCE OF PLANTING

Due to the fact that many questions relative to planting distances are received by the Horticultural Department every year, the following experiment was planned and conducted for 2 years to supply definite information on the proper spacing to use. The plants were grown by the method described in the previous section and were set in a bed 7 feet by 50 feet by 8 inches deep and having a concrete bottom. There were 4 rows of plants in the bed. The bed was divided into three approximately equal parts, and the plants were set 16 inches, 20 inches, and 24 inches, respectively, in the row in each part. Table 4 presents the data gathered on yields but does not show certain rather important effects upon the plants themselves. Where the plants were set close together, they soon covered the ground and crowded each other so that it was difficult to care for them properly. Later, this section consumed more water and showed signs of nitrogen shortage before either of the other two. The plants in it were the last to begin blooming. The first cluster set fruit more completely than either of the other two blocks, but the succeeding clusters were not quite as well filled.

TABLE 4.—Distance of Planting Tomatoes

Planting distance	Yield per plant		Yield per sq. ft. area	Av. weight of fruits	Percentage first grade
In.	*No.*	*Lb.*	*Lb.*	*Oz.*	*Pct.*
16x24	22.0	6.72	1.43	5.60	74.64
20x24	24.6	8.03	1.71	5.12	84.55
24x24	25.1	8.82	1.50	5.60	86.38

On the plants set the farthest apart, nearly the same number of fruits matured per plant as on those placed at the intermediate distance. The weight of fruit per plant was also a little more, but in weight per square foot of space the intermediate distance was the best of all three spacings. There was little difference in the average size of fruits in either treatment, but in percentage of first grade fruit the plot having the closest spacing had the lowest percentage. The plot having the widest spacing had the highest percentage of first grade fruits, but it is believed that the intermediate spacing is most economical with its high yield per square foot, as well as its satisfactory percentage of first grade fruits.

POTTED VERSUS TROWEL-SET PLANTS

It is the common practice among greenhouse tomato raisers to set the plants with a trowel or spade. It is claimed by some of them that it is less expensive and easier to do, that less space is needed in which to raise the plants, and that there is less weight to handle in transporting them since most of the soil falls off the roots. Those growers who raise their plants in pots claim that the plants grow faster after setting in the permanent beds, if they have been moved without disturbing the roots; that there is no check in the growth of the plants and, therefore, no readjustment is necessary. It is also claimed that the tomatoes mature and ripen earlier if the plants have been raised in pots and that the total yield is greater.

TABLE 5.—Potted versus Trowel-set Tomato Plants

Treatment	Yield per plant		Av. weight of fruits	Yield per sq. ft.	Percentage first grade	Percentage loss due to treatment
	No.	*Lb.*	*Oz.*	*Lb.*	*Pct.*	*Pct.*
Potted	27.0	8.76	5.12	1.75	80.03	....
Trowel-set	22.6	7.37	5.12	1.47	81.78	−15.86

Tests were conducted for 2 years in the Station greenhouses to get comparable sets of data upon this problem. Table 5 presents one set of yield data comparing the results of the two systems. All of the plants came from the same lot of seed sown December 1. As soon as the seedlings were large enough, they were transplanted to flats, being spaced 2 inches by 2 inches apart. After the leaves had practically covered the spaces between the plants, they were again transplanted. A part was set in 4-inch pots and another part in deep flats at approximately 4-inch distances. They were then grown at cool temperatures, 50° to 55° F., until ready to set in the bed. All of the plants were set in the bed January 26, when the plants were about 6 inches high.

The potted plants began blooming February 13, and by March 2 most of the buds on the first clusters had opened. The first ripe fruits were picked from them on April 10. The trowel-set plants began to bloom on February 27, and by March 2 from one to two blossoms were open on 50 to 60 per cent of the plants. There were no ripe fruits until April 20. The season for both treatments ended the same day, July 8.

These data bring out certain additional differences besides those mentioned in the preceding paragraph. The potted plants matured a larger average number of fruits and more than 15 per cent greater weight. The average size of the fruits was the same, and the difference between the percentages of first grade fruits between the two lots is not significant. The weight of total fruit per square foot of bed space is significant and, when computed on an acre basis, should prove to be a considerable amount. A very important point has arisen from this study in that the increase in yield is largely due to earliness of ripening, which, consequently, means higher prices at only slightly increased cost of production.

THE USE OF NITROGEN FERTILIZER DURING THE HARVESTING SEASON

The spring tomato crop in the greenhouse is very apt to suffer from insufficient nitrogen before it is completely developed. The tomato plant is of such a nature that it is impractical to apply all of the nitrogen to the soil in the greenhouse before the plants are set out; this has been tried many times and has usually been unsatisfactory. Such factors as short days, cloudy weather, lowered temperatures, and possibly too much moisture cause tomato plants to grow vegetatively with the loss of blossoms on one or more of the lower clusters.

Symptoms of nitrogen deficiency are characteristic and are easily recognized. They commonly begin to appear in most greenhouses about the time the fourth cluster is in bloom. As a rule, if the blossoms have set on the first cluster and the fruits have started to grow, the fruits will be nearing maturity by that time and the need for nitrogen is very great. Consequently, most of the nitrogen that is available to the plants in the soil is used up by the fruits and not enough is obtainable to provide for normal growth in the tops of the plants. Under such a condition several things are likely to happen. In the first place, a visible stunting occurs, which is accompanied by a change from the dark green color of a vigorously growing plant to a pale yellowish green. The stem, leaf petioles, and leaves are reduced in size and become tough and woody. In most cases there is also a considerable development of purple color in the stems, leaf petioles, and the under sides of the leaves. As the condition becomes worse, the color in time may become almost a lemon yellow.

In the second place, the effect of nitrogen deficiency upon the fruits is very marked. The tomato blossoms fail to set normally in many cases, and whole clusters of buds may dry up and fall from the upper portion of the plants if the lower clusters are full of rapidly growing fruits. Then, as the mature fruits are removed from the base of the plants, more of the nitrogen ascends the stalk, and scattered fruits will then set in the tops of the plants and grow slowly. Nitrogen deficiency affects the size and number of fruits in the tomato more than it does their shape. The fruits on nitrogen-deficient plants usually are smooth, solid, and well colored if adequate amounts of the other fertilizer elements are present, but they are usually much smaller in size and fewer in number than when adequate amounts of it are available. The grower who can recognize the early symptoms of nitrogen deficiency is able to prevent a serious deficiency by applying a readily available nitrogen fertilizer as a side-dressing along the rows just previous to the next irrigation. Numerous instances of increases in yield are on record among the growers, following the use of nitrogen fertilizers on the tomato crop. Table 6 presents the data obtained in the Station greenhouses with the use of ammonium sulfate as a side-dressing at the rate of 250 pounds per acre each week for eight applications. The soil was a good compost to which manure, superphosphate, and potash had been added. When three or four clusters of blossoms had set and started to grow, the above symptoms started to develop but were corrected by the additional nitrogen.

TABLE 6.—Nitrogen Fertilizer as a Supplement to Summer Tomatoes

Treatment	Yield per plant		Av. weight per fruit	Yield per sq. ft.	Increase due to treatment
	No.	*Lb.*	*Oz.*	*Lb.*	*Pct.*
Untreated	30.85	9.76	5.05	1.95	....
Ammonium sulfate	33.03	10.30	4.99	2.06	5.64

These data indicate that even on a highly productive soil increases may be obtained when nitrogen is supplied. There were increases in numbers and total weight of fruits per plant, as well as in total yield per square foot of ground. The difference in size of fruits is insignificant in this instance, but many instances have been found in commercial greenhouses where the size of fruits has been increased very much by nitrogen supplements.

Another test was conducted in a large commercial greenhouse in which the fruits were separated into the commercial grades. The soil was fertilized with a liberal application of manure, superphosphate, and potash. Later, when the nitrogen supply became inadequate, sulfate of ammonia was applied as a side-dressing along the rows. The applications were at the rate of 300 pounds per acre at weekly intervals during the picking season.

TABLE 7.—Greenhouse Tomatoes Treated with Ammonium Sulfate

Grade	Untreated		Treated	
	Lb.	*Oz.*	*Lb.*	*Oz.*
Large	99	10	127	6
Medium	274	4	308	2
Choice	360	11	447	7
Culls	82	8	117	5
Total	817	1	1000	4

The plots under experiment were about 8 feet wide, 50 feet long, and contained 4 rows of tomatoes. During the picking season the treated block produced 183 pounds 3 ounces, or 18.31 per cent, more fruit than the untreated one. There was a striking difference in the appearance of the plants in the two blocks. (See Figures 3 and 4.) The plants in the treated block were large, vigorous, and dark green in color. The fruits developed rapidly and ripened in normal time. The plants in the untreated block became light yellowish green in color early in the season, and subsequent growth was slow. The plants were late in ripening their fruits after the first two or three clusters were matured. Fruits in the upper clusters were greatly retarded in growth and slow in ripening. Though the nitrogen never became so scarce that growth stopped completely, the supply was so deficient that it was far below the needs of the plants. By the addition of nitrogen to the treated block, the growth of the plants was speeded up and normal ripening of the fruits was induced earlier than in the block where it was omitted. Though nitrogen in excess is generally believed to delay ripening of fruits in certain plants, it was found actually to put these tomato plants into such a condition that earlier ripening was induced, where the previous nitrogen supply was inadequate.

TABLE 8.—Effect of Supplementary Side-dressings with Sulfate of Ammonia on the Percentages of Tomato Fruits in Each Grade

Grade	Untreated	Treated	Difference
	Per cent	*Per cent*	*Per cent*
Large	12.19	12.73	0.54
Medium	33.56	30.80	−2.76
Choice	44.14	44.73	0.59
Culls	10.11	11.74	1.63

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Fig. 3.—(Above) The effect of nitrogen fertilizers on the growth and yield of tomatoes during the harvesting period. Those plants on the left received weekly applications of 250-300 pounds per acre of sulfate of ammonia; those on the right received no supplementary nitrogen.

(Below) Side view of a row of treated tomatoes similar to those above. Note large fruits on the lower clusters, as well as vigorous looking tops in the plants.

Fig. 4.—(Above) Well developed tomatoes on the fifth clusters of the plants fertilized with nitrate of soda shown on the left in Fig. 3 (above).

(Below) Lack of development of the tomato fruits on the fifth clusters of the unfertilized plants shown on the right in Fig. 3 (above). Compare also with the fruits on the above plants.

The percentage differences in the grades between the fruits in the treated and untreated blocks were small and insignificant. It seems that under the conditions of this experiment, where the plants were not deficient in any element except nitrogen, supplementary nitrogen applications did not affect the percentages of fruits in each grade but did affect the size and number of them as seen in Table 7.

TABLE 9.—Effect of Side-dressings with Sulfate of Ammonia on the Percentages of the Total Crop Harvested, by Months

Period	Untreated	Treated
	Per cent	*Per cent*
June	34.14	36.57
July	54.88	54.69
August (15 days)	10.98	8.74

Supplementary applications of nitrogen increased somewhat the earliness of the crop, as shown in Table 9. Under mid-season production there was practically no difference, but the treated plants ripened more fruits in June and less in August than the untreated ones. This should be of interest to all tomato growers, as the prices are usually much more favorable early in the season than in the latter part, when there is greater competition with field-grown tomatoes.

LEAF PRUNING IN RELATION TO THE SIZE OF FRUIT, TIME OF MATURITY, AND YIELD IN TOMATOES

Tomato growers in the greenhouses of various sections of the vegetable forcing regions have practiced leaf pruning for many years. Perhaps the most common reason given for leaf pruning is its supposed effect upon the development of tomato leaf mold (*Cladosporium fulvum* Cke.). It is assumed that by removing the lower leaves of the plants the surface of the soil or mulch will dry off more rapidly following an application of water by permitting a more rapid circulation of air. Tomato leaf mold is controlled fairly well by maintaining a low relative humidity in the atmosphere. A dry surface soil with an ample amount of water in the subsoil does not insure a low relative humidity because far more moisture is transpired through the leaves than evaporates from the soil; so leaf pruning has failed to give any measurable degree of control of leaf mold. Lowered relative humidity is obtained by proper ventilation and by judicious manipulation of the heat.

The practice also is followed in some cases in the absence of the disease in order to make it easier to see the fruits at picking time.

Many times little or no attention is paid to the size or stage of maturity of the fruits when the pruning is started, but normal leaves are torn off the plants from 1½ to 3 feet above the ground, leaving the stem and one or more clusters of fruit exposed. Since the leaves are the organs in which the sugars are made that produce the energy for growth, and when the sugars combine with nitrogen, protein may be formed for the new tissue, it is important to know what the effect will be on the crop if leaf pruning is practiced.

The following experiment was started in the spring of 1928 and was carried on through four spring and three fall crops. The method and the amount of pruning remained the same throughout the entire period, but the stage of maturity at which the pruning was done was varied in order to determine if this factor might produce different effects. It will be observed in studying the data in Table 10 that the stage of maturity at which the pruning was done appeared to affect the results materially.

TABLE 10.—Tomato Leaf Pruning

Treatment	Average yield per plant		Av. weight of fruits	Yield per sq. ft.	Percentage first grade	Percentage difference in yield
	No.	Lb.	Oz.	Lb.	Pct.	Pct.
Spring Crop, 1928. Pruned when first fruits were ¾ inch in diameter						
Unpruned	26.3	10.28	6.24	2.20	85.23	....
Leaf tips removed	26.1	9.62	5.89	2.06	83.64	— 6.42
Leaves removed to 1st cluster.	25.4	9.52	5.92	2.03	84.16	— 7.50
Leaves removed to 2nd cluster	22.9	8.41	5.86	1.81	82.84	—18.19
Fall Crop, 1928. Pruned when first fruits were ¾ inch in diameter						
Unpruned	10.6	6.24	9.41	1.34	88.48	....
Leaf tips removed	9.0	5.66	10.08	1.21	87.26	— 9.34
Leaves removed to 1st cluster.	8.0	4.56	9.12	0.98	85.83	—26.90
Leaves removed to 2nd cluster	7.5	4.04	8.61	0.87	85.66	—35.12
Spring Crop, 1929. Pruned when first fruits were half grown						
Unpruned	34.4	10.54	4.89	2.11	90.26	....
Leaf tips removed	31.4	9.77	4.97	1.95	92.31	— 7.5
Leaves removed to 1st cluster.	30.8	9.96	5.17	1.99	92.00	— 5.6
Leaves removed to 2nd cluster	29.2	9.64	5.28	1.92	94.12	— 9.0
Fall Crop, 1931. Pruned when first fruits were mature						
Unpruned	28.0	8.10	4.62	1.62	77.74	....
Leaf tips removed	27.0	8.37	4.96	1.67	82.07	+ 3.3
Leaves removed to 1st cluster.	27.0	8.68	5.14	1.73	85.27	+ 7.2
Leaves removed to 2nd cluster	27.0	9.04	5.35	1.80	87.60	+11.6

The experiment consisted of four plots, each plot containing 28 plants selected from a large number of the same variety in order to secure uniformity. They were grown in 4-inch pots and were set in the beds as soon as they were 5 or 6 inches high. They were trained to the single stem method and supported on stout strings. In Plot 1, the leaves were left unpruned as a check. In Plot 2, the tip half of each leaf below the first cluster was pruned off, after which there was no further pruning. In Plot 3, all of the leaves were pruned off below the first cluster, and the plants were left without further pruning. In Plot 4, all of the leaves up to the second cluster were pruned off, after which the plants were left unpruned as in the other cases. (See Fig. 5).

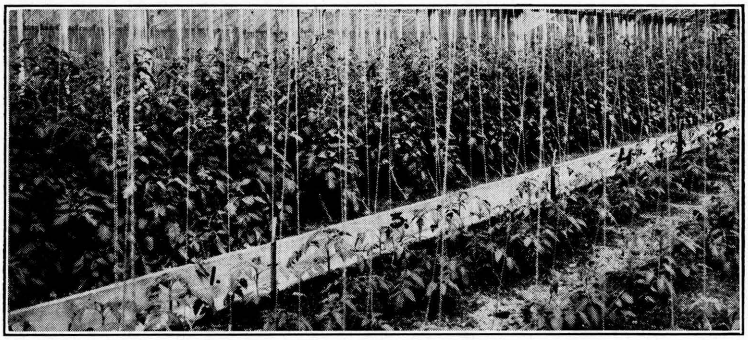

Fig. 5.—Leaf pruning experiment.

Plot 1, unpruned; Plot 2, leaves tipped; Plot 3, leaves pruned to first cluster; Plot 4, leaves pruned to second cluster

In 1928, in both the spring and fall crops, the pruning was done when the third cluster was in bloom and the first fruits on the lower clusters were about ¾ inch in diameter. The plants and fruits were apparently free from disease. In 1929, the pruning was delayed until the first fruits on the lower clusters were more than half grown, and, in 1930 and 1931, it was delayed still further until the earliest fruits on the lower clusters had about stopped growing, and, in fact, a few had ripened. The data for the spring crop of 1930 tended to show the same effects as were produced in 1931, but they were omitted because a number of plants died from Fusarium wilt during the season; thus, the yields were not reliable. The results of leaf pruning in the fall tended to show the same serious effect in all three crops; therefore, only one set of figures is included in Table 10 to avoid unnecessary repetition.

As shown in Table 10, the spring crop of 1928, where the leaf pruning was done when the earliest fruits were about ¾ inch in diameter, suffered the greatest loss. It was correlated with the amount of foliage removed; where the leaves were removed to the second cluster, the decrease was more than 18 per cent of the unpruned lot. Further study shows that the loss was due to fewer fruits setting and maturing, as well as to smaller fruits. The decrease was reflected in lower total weight of fruit per plant, a reduction in yield per square foot, as well as a lower percentage of first grade fruit in proportion to the severity of pruning.

In the fall crop, the pruning was done at relatively the same stage of growth as in the spring crop of 1928. The results were similar, except that the loss was greater. The loss was shown again in a reduction of the number of fruits set and harvested; and also, in general, the size of fruit was reduced in proportion to the severity of pruning. This does not quite hold for Plots 2 and 3 where the differences were too small to be significant, but in Plot 4 the fruits have been reduced in size about 10 per cent. In the average total weight per plant, the reduction was very significant, and in Plot 4 the actual decrease was more than 35 per cent. The extreme reduction was also shown in yield per square foot and in the percentage of first grade fruits. These striking results obtained in the fall crop may be explained by the amount of sunlight the plants received. In the spring, when the daylight period was lengthening and the quality of the sunlight was improving a part of the injury appeared to be overcome by readjustments within the plants, but in the fall these conditions became just the reverse. The daylight period became shorter and the light lower in intensity because of the general atmospheric conditions concomitant with the approach of winter. The lower leaves were needed to supply the plants with enough carbohydrate materials to form a reserve supply for growth. When these organs were removed in the spring, there was an arresting of the growth processes until new leaves could be reproduced in the tops of the plants, after which the plants resumed growth. During this period of readjustment the fruits had time to mature but were smaller in size. The season then closed in midsummer with fewer fruits formed and developed, because of the lost time following the pruning period. When the pruning was done in the fall, the most effective leaves were removed. More injury was done to the plants than in the spring because the days were so short and the intensity of the light so low that the time required for reconstructing new plant parts to replace those removed was so long that the season closed before they could be grown.

That leaf pruning tended to reduce the quantity of reserve carbohydrate materials and to increase the length of time necessary to readjust the plant to its normal balance was shown by the behavior of the plants in the spring crop of 1929. In this test there was also the same tendency towards loss of fruit and decreased total yield per plant as in the previous cases but on a much smaller scale. The leaves were not pruned off in this case until the first fruits on the lower cluster were approximately half grown. By this time, then, it appeared that the young leaves in the tops of the plants were sufficiently large and the plants well enough developed to shorten materially the time necessary to restore the balance between the carbohydrate reserves and the available minerals and moisture in the soil. Therefore, it was reasonable to expect smaller differences among the several treatments. Under the conditions of this test, the loss by leaf pruning was between 5 and 9 per cent of the yield of the unpruned plot. Though the decreases were small, they were considered significant when the tendency of the experiment as a whole was considered.

In the spring crops of 1930 and 1931, the pruning was delayed until many of the fruits on the lower clusters were fully grown and in some cases a few fruits were ripe (April 10). By this time the plants were between 5 and 6 feet tall and had six or seven clusters set or in bloom. The leaves were large three-fourths of the way up the stem when the pruning was done. The data obtained from the 1931 crop show that there was a slight decrease in the average number of fruits set per plant, but the total weight of fruit harvested increased steadily in proportion to the amount of leaves removed. In addition, the size of the individual fruits, the yield per square foot of greenhouse space occupied, and the percentage of first grade fruits increased in proportion to the severity of the pruning. Instead of a loss in yield as reported in each of the previous cases, there was an increase from 3 to more than 11 per cent over that of the unpruned plants. The same tendency towards increased yields was observed in 1930, but the results were not so striking, probably because of the interference of disease.

Returning to the principle that leaf pruning reduces the amount of available carbohydrates and makes necessary an increased time period to restore the balance between the carbohydrates and nitrogen within the plant, it appeared that these plants had now progressed beyond the stage where the leaves below the second cluster at least were necessary for the normal functioning of the upper portions of the plants during the late spring and summer. Under the conditions of the preceding experiments, the removal of healthy leaves up to the second cluster of fruit had been accompanied by decreases in the number and size of the fruits set and harvested when the pruning was done while the fruits were small.

There were also decreases in the percentages of first grade fruit at all stages of growth up to the time the fruits on the lower clusters approached maturity. After that stage had been reached the yields tended to increase following leaf pruning. The behavior of the plants suggested the possibility of a reduction of carbohydrates with the removal of the leaves, which automatically raised the nitrogen supply, relatively, within the plants. The removal of a part of the leaves will tend to reduce the carbohydrate reserve and restore the normal carbohydrate-nitrogen relation in the plants of the spring crop which had been destroyed by an excessive accumulation of carbohydrate materials in the leaves during the long days with bright sunshine. This carbohydrate supply stops fruit development if it becomes too great when the nitrogen supply is insufficient within the plants. The plants received nitrogen (sulfate of ammonia) as side-dressings at regular intervals, but that does not preclude the possibility that there may have been an insufficient supply available within the plants to maintain fruit production.

Leaf pruning was shown to be injurious in the preceding experiments in most cases and only the lower leaves may be removed in the spring crop when the days are long and the light is intense. There is also some evidence that the removal of the lower leaves may be justified when the nitrogen supply becomes inadequate.

Leaf pruning in the fall had no effect upon the time of ripening of the fruits. In each case ripe fruits were picked from each treatment on the same date. In the spring, leaf pruning tended to delay ripening when it was done early, but, when delayed until the early fruits were half grown or larger, there was little or no effect upon the time of ripening. There was a delay of 3 days in Plots 3 and 4 in the 1931 series, but in the 1929 series all plots produced ripe fruits the same day. It has also been suggested by some that leaf pruning may prevent blossom end rot, but an examination of the records did not show any correlation in this respect. There was just as much on the pruned as on the unpruned plots.

MULCHING GREENHOUSE TOMATOES

Mulching is an old established practice that started in the early days of vegetable forcing in this State. The idea probably was adopted from the rose houses in northeastern Ohio and the materials used were principally animal manures containing more or less straw.

Justification of the cost has been ascribed by the growers to a number of things: (a) conservation of moisture, (b) saving of labor in frequency of watering, (c) keeping the soil cool in hot weather, (d) saving labor by eliminating cultivation, (e) keeping down weeds, (f) preventing packing of soil when walked on while wet, and (g) supplying minerals by leaching during the watering operations. The variation in the behavior of the mulched crop has been so wide that often the predicted result failed to appear, and this gave rise to doubts about the validity of these claims.

New experiments were laid out in the Station greenhouses at Wooster and in a greenhouse on the Cleveland City Correction Farm at Warrensville, Ohio. The bed at the Station had a concrete bottom and at Warrensville was the ordinary flat, open soil type with a yellow clay subsoil. At Warrensville the experiment was planned to include the mulching materials that are commonly used in the Cleveland district. These were well-rotted horse manure, fresh strawy horse manure, fresh horse manure in which wood shavings were the absorbing material, and steamed garbage from the city disposal plant. Dried tobacco stems are occasionally used; so they were included. Then, in order to get the effect of carbohydrate materials that are very low in nitrogen, chopped dry corn stover was added to the group. The stover had stood exposed to the weather over winter and was thoroughly leached.

Well-grown tomato plants were planted in the bed April 3, and the manure and corn stover mulches were applied May 18. The garbage and tobacco stems were applied May 25, because they could not be obtained earlier. Two plots were left untreated to serve as checks. All of the plants were growing rapidly when the mulches were applied and they had the characteristic dark green color of healthy plants. By May 31 (13 days) when they were examined, distinct yellowing in the tops of the plants was beginning to appear in the three manure plots. It was the most pronounced in the plot mulched with fresh strawy manure and the least in that one with the well-rotted manure. The plants in the checks were a dark green color from the base to the top and were still growing rapidly. The plants in the plots mulched with garbage, tobacco stems, and corn stover appeared at this date to be in as good condition as the checks, but by another week they showed in every case the same symptoms of yellowing and retarded growth in the tops as shown in the manure-mulched plots. This difference in general appearance between the mulched and unmulched plants maintained itself throughout most of the season.

The unmulched plants continued to grow more rapidly, set more fruit, and reached the height at which they were topped more quickly than the mulched ones. The mulched plants continued to grow, however, and set fruit during the season. They finally yielded about the same amount as the unmulched plants. The indications were that, if the check plants had not been topped but allowed to continue to grow for a longer time, the mulched plants would not have equalled the checks in yield. The results are presented in Table 11.

TABLE 11.—The Effect of Some Mulching Materials Upon Greenhouse Tomatoes, Warrensville, 1928

Treatment	Av. yield per plant		Av. weight of fruit	Percentage first grade	Percentage difference in yield
	No.	*Lb.*	*Oz.*	*Pct.*	*Pct.*
Rotted manure	20.3	4.47	3.52	65.10	− 4.69
Fresh strawy manure	19.9	3.53	2.88	61.45	−24.73
Fresh shaving manure	23.4	5.24	3.55	57.34	+11.72
Check	24.6	4.69	3.04	48.42	....
Steamed garbage	23.4	4.56	3.10	49.92	− 2.77
Tobacco stems	21.5	4.74	3.52	54.46	+ 1.06
Corn stover	20.0	4.93	4.16	65.06	+ 5.33

The first picking of ripe fruits was made on June 30 and picking was continued at regular intervals until August 30 when the plants were removed to prepare the ground for a fall crop. The short season accounted for the low yields, but the responses of the tomatoes to the mulches appeared to be characteristic. The yields of the two check plots were nearly equal, and the average yield of the two plots was used as the check. The unmulched plot yielded a larger number of fruits than any of the other treatments, but the size of the fruits was a little smaller than most of the others. The plot having the fresh strawy manure yielded the lowest in both number and weight of fruits. The plot having the fresh shaving manure yielded the largest fruits but produced only as many fruits as the garbage-treated plot.

The most surprising result was the response made to the application of well-rotted horse manure. These plants yielded less than would be expected if well-rotted manure contained as much soluble minerals as is commonly supposed. Since so few fruits set, it was natural that they should be larger in size. This was seen to be the case in some of the other treatments as well. Although as many fruits set on the plants mulched with garbage as on those mulched with the shaving manure, they were much smaller, which caused a lower yield for the treatment.

Tobacco stems have been used for mulching purposes in a few instances but never became popular. Corn stover probably has never been used before, but this material and tobacco stems were tried to see what effect there would be on the availability of the nitrogen supply by the action of bacteria in the soil in breaking down the cellulose material. Fewer fruits were set on these plots than in most of the other treatments, but the fruits became so large and heavy that they outweighed those of all the other treatments except those of the fresh shaving manure. This led to the inference that the bacteria acted so slowly on these materials that nitrogen deficiency never became a seriously limiting factor. This seemed to be the case, as the corn stover did not break down rapidly. Since the tobacco stems were dry and brittle and were crushed into fine bits by the continued tramping of the laborers, the mulch disappeared.

Soil biologists have found that the detrimental effect of applying highly carbonaceous mulching materials around growing plants is due to a temporary fixing of the soluble nitrogen in the mulch and upper layers of the soil by the soil organisms that decompose the mulching materials. Soils only moderately supplied with soluble nitrogen become deficient more quickly than those having an abundance of it. The kind of mulching material used also bears a direct relation to the action. Fresh strawy manure reacted quicker and carried the injury further, presumably because of a larger supply of soluble carbohydrates. In applying water to the mulch a certain amount of carbohydrate material, being soluble, was leached into the upper soil layers where it was used by the soil organisms as a source of energy for growth. Since the soil organisms need nitrogen for growth, are better distributed throughout the soil than the plant roots, and compete with the plants for nitrogen, a deficiency resulted. This seemed to be the explanation for the behavior of the plants mulched with fresh strawy manure and would account for the striking decrease in yield. Repeated tests with the diphenylamine solution have shown that nitrate nitrogen is as low under such mulching materials as five to seven parts per million of soil. This is entirely too low for satisfactory plant growth.

The wood in the shavings is also of carbohydrate origin, but it is much less soluble in water than the carbohydrates of the straw; hence, bacterial action proceeds very slowly in decomposing it, and the nitrogen deficiency thus produced was of short duration. The plants soon recovered sufficiently to mature a larger crop than under any of the treatments, although they were always light green in color. The plants apparently were able to use the mulch as a source of fertility, because the gain in weight was more than 11 per cent. This point was of considerable interest since it has been repeatedly shown at the Experiment Station at Wooster that cattle manures exposed to weathering for 3 to 6 months lose, on an average, 44.05 per cent of their potassium, 32.19 per cent of their nitrogen, and 14.07 per cent of their phosphorus by leaching; that is, a loss of most of the water soluble or available nutrients. This fact added valuable support to the claim that mulches of weathered manures are a poor source of fertility for greenhouse use. The insoluble portion that remains is unavailable and will not become available until the manure decomposes.

The rotted manure in this experiment was taken from the local barn yard and had been subjected to leaching for several months. Hence, most of the soluble fertilizing value had leached away. Some coarse particles of straw remained which probably served to carry on the nitrifying action and in that way caused a temporary nitrogen deficiency. Relatively few fruits set per plant, but as the nitrogen became available they grew somewhat larger than those on the check treatment, indicating that nitrogen was again being released. The effects of steamed garbage, tobacco stems, and corn stover were hardly significant. The nitrogen deficiency symptoms previously mentioned remained throughout the experiment. Though the number of fruits set in each case was less than that of the check, the size became larger, indicating again that the nitrifying action was slow and the deficiency not particularly serious.

At Wooster, the mulching experiments were confined to one material—partially decomposed cattle manure —on both sterilized and unsterilized soils previous to planting. In both cases the soil was good greenhouse soil of compost origin. Both beds were given an application of manure equivalent to about 50 to 55 tons per acre and spaded in before the plants were set. The effects are contrasted in Table 12.

Where the soil was unsterilized the detrimental mulching effect began to show up in about 5 weeks after the mulch was applied and became serious in mid-season. There was a loss in weight of 14.26 per cent of the crop; fewer fruits were set on each plant, and they were smaller in size, with a smaller percentage of first grade fruits; and there was a decrease in the early yield. Though some fruits were picked from each block on each day, more were picked from the unmulched block than from the mulched. At the end of the first 2 weeks of the picking season, 13.3 per cent more fruit had been picked from the unmulched block.

In the bed where the soil was sterilized, there were slightly fewer fruits set per plant in the mulched plot, but they became larger and the average total weight per plant was 12.62 per cent greater than that of the unmulched, indicating that some benefit may be obtained from mulching on sterilized soil, due, probably, to the reinoculating effect of the manure. Furthermore, more fruits were set under both unmulched and mulched conditions in the unsterilized soil than in that which had been previously sterilized. The total average yield per plant was greater, which, of course, increased the yield per square foot of greenhouse area.

TABLE 12.—Effect of Manure Mulch on Greenhouse Tomatoes, Wooster, 1930

Treatment	Yield per plant		Av. weight of fruits	Yield per sq. ft.	Percentage first grade	Percentage difference
	No.	Lb.	Oz.	Lb.	Pct.	Pct.
Unsterilized soil						
Unmulched	26.32	6.45	4.97	1.29	82.03	....
Mulched	23.46	5.53	3.77	1.10	77.21	—14.26
Sterilized soil						
Unmulched	16.20	4.29	4.22	0.86	79.74	....
Mulched	15.40	4.91	5.09	0.98	89.95	+12.62

In the second paragraph of this discussion on mulches, a number of things were listed as reasons for the greenhouse men using mulches. It was thought that mulching saved watering as often and that water was prevented from evaporating from the soil by the mulch. Under the conditions of these experiments this did not seem to be the case. The plants in the mulched blocks used the same quantity of water as those in the unmulched, and at the end of the experiment the soil in both blocks appeared to be equally dry. The shading of the ground by the plants seemed to off-set any protective action by the mulch. The largest part of the soil water is passed up the stem and out through the leaves of the plant by transpiration, and a relatively small part evaporates from the surface of the soil after the plants are large enough to shade the ground. Mulching in the Station greenhouses has lowered the temperature of the soil only about $1\frac{1}{2}°$ to 2° F. below that of the unmulched soil, which is not enough to give much protection to the plants if high soil temperatures ever become important. When the air temperature in the greenhouse was about 100° F., the soil temperature was about 73° to 75° F. in the unmulched area. Mulching does save the labor of cultivation and to some extent tends to keep down weeds, but from the standpoint of cost it would not pay to mulch for this purpose. It prevents the formation of a crust on the surface of the soil where workmen walk repeatedly, but, under all of the experiments at Warrensville and Wooster, mulching has not made the soil work up any easier. Finally, there seems to be little, if any, of the soluble fertilizer elements left in the manures when they are brought into the greenhouse as they have nearly all been heavily leached by rains in the compost yard.

The cost of manures and the labor of applying them will more than off-set any benefits from their use as a source of fertility, and most of the other so-called "advantages" are thought to be groundless. There are at least four cases, however, where mulching is believed to be of distinct value and, consequently, is recommended where the conditions demand it:

1. If a greenhouse is located on extremely rich soil, containing a large supply of available nitrates, mulches containing soluble carbohydrates may need to be used with early tomatoes to reduce the nitrate supply so that the plants will set fruit. Later feeding with nitrogen will then be necessary to bring the crop into full production.

2. On rolling or sloping ground, mulches are sometimes advisable as an aid in retaining water. Water may run off so fast that the soil may not become sufficiently moistened on the higher parts to meet the needs of the crop.

3. Mulches tend to keep the surface of the soil moist and prevent cracking in heavy soils. Cracking breaks the roots and may cause considerable injury in severe cases.

4. Where it has been necessary to sterilize the soil before a crop is to be planted, mulching with manure restores the soil organisms quickly and brings the soil back to its normal action in time to benefit the present crop greatly.

SUMMARY

Tomato seed for the early spring crop in the greenhouse should be sown about the first of December and the plants transplanted in the beds the latter part of January or early in February to obtain the largest crop under Ohio conditions.

Tomato plants transplanted to the beds as late as the first of March do not produce ripe fruits until quite late in the season. The blossoms in the upper clusters of these plants may also be injured by the long days and high summer temperatures so much that they fail to set fruit, thus reducing the total yield of the crop considerably.

When tomato plants are held in small clay pots in the plant house for several weeks after they have reached the height of 6 to 8 inches, they are apt to become woody, light colored, and stunted. The buds on the first cluster, and sometimes on the second, are injured so that the flowers do not set fruits well. Sometimes the blossoms do not set at all; at other times they may set fruits, but the fruits may remain small and imperfect in shape.

Tomato plants should be planted far enough apart so that sunlight and air can reach them readily. Close planting reduces the number of fruits set; the maximum yield of fruits per square foot of greenhouse space covered was obtained where each plant occupied about 3½ to 4 square feet of space.

Tomato plants grown in 4-inch pots and transplanted to the beds without disturbing the roots grew faster than those which were grown in flats and transplanted to the beds with a trowel.

The potted plants produced ripe fruits earlier and produced a larger total yield than the trowel-set plants.

By applying nitrogen fertilizers to tomatoes during the harvesting period the crop may be materially increased, the size of fruits increased, and the quality considerably improved.

Leaf pruning, in most cases, is injurious and causes a reduction in yield. However, there is some evidence that the lower leaves may be removed with profit late in the spring when the nitrogen supply has been considerably reduced.

Mulches of strawy manures often produce nitrogen deficiency in the soil, which causes a reduction in yield.

When it becomes necessary to use a mulch for a specific purpose, nitrogen fertilizers may be used to restore the plants to normal production.

Manures may be used as a mulch or may be spaded into soils following soil sterilization to inoculate the soil with the same kind of organisms that were killed by the sterilization.

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